- PATENT -

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT:	Sartori et al.	EXAMINER: Dean, R.
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ENTITLED:	METHOD AND APPARATUS FOR RELAY FACILITATED COMMUNICATIONS	

Motorola, Inc.
Corporate Offices
1303 E. Algonquin Road
Schaumburg, IL 60196
April 24, 2007

DECLARATION UNDER 37 C.F.R. § 1.131

Commissioner for Patents
P.O. Box 1450
Alexandria, Va. 22313-1450

Dear Sir:

Now comes Eugene Visotsky, who declares and states:

1. That I am an inventor of the subject matter claimed in the above-identified U.S. Patent application.

2. Prior to March 31, 2003, I had completed the invention described and claimed in the above-identified U.S. Patent application, as evidenced by the following facts: Prior to March 31, 2003, while in the course of research and experimentation at Motorola, Inc., and in association with Philippe Sartori, Brian Classon, Kevin Baum, Mark Cudak, and Vijay Nangia, my co-inventors in the above-identified U.S. Patent application, I had prepared and characterized an invention for sending and receiving multimedia information in a communication system as evidenced by paper dated November 25, 2002 that we submitted to Motorola, Inc., as part of a Patent Disclosure form, dated November 26, 2002. A copy of the paper and a redacted version of the Patent Disclosure form are attached to this Declaration. Various embodiments of our invention provided a method of relay facilitated communications including, at a wireless relay resource, combining received portions of relayed transmissions from the transmitter using HARQ to reconstruct the transmission, wherein combining received portions of relayed transmissions from the transmitter using HARQ to reconstruct the transmission may include combining and decoding received portions of relayed transmissions from the transmitter to reconstruct the transmission and wherein the method may further include relaying a reconstructed transmission to the base site. Another embodiment of our invention provided a method of relay facilitated communications including combining received portions of relayed transmissions from the wireless relay resource with portions of transmissions from the transmitter to reconstruct the transmission, wherein combining received portions of relayed transmissions from the wireless relay resource with portions of transmissions from the transmitter to reconstruct the transmission may include combining received portions of relayed transmissions from at least one wireless relay resource with portions of redundant transmissions from the transmitter to reconstruct the transmission. Yet another embodiment of the invention provided a method of relay facilitated communications including automatically determining whether to allocate a wireless relay resource that will demodulate and decode the transmission from the transmitter to provide decoded information, determine whether the transmission has been

likely correctly received, re-encode the decoded information to provide re-encoded information, and transmit the re-encoded information to the base site, and may further include not transmitting to the base site any relayed transmissions that would be based upon transmissions that were likely not correctly received.

3. The date of the Patent Disclosure form that Philippe Sartori, Brian Classon, Kevin Baum, Mark Cudak, Vijay Nangia, and I submitted to Motorola, Inc., that is, November 26, 2002, is prior to March 31, 2003, that is, the priority date of the Periyalwar patent application, U.S. patent application publication no. 2004/0199204, cited by the Examiner in rejecting our application in an Office Action dated November 16, 2005.

4. The undersigned Declarant declares further that all statements made herein of his own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of this application or any patent issuing thereon.

5. Further Declarant saith not.

Eugene VISot ______________ 04/27/07 ______________

Eugene Visotsky Date

Disclosure CML00917M (16828)

Printable Version

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Department:	AE598
Location:	IL02
Submit Country:	USA

[View Changes Log]

Workflow

Role	Name	Action
First Innovator	Philippe Sartori	Verification Complete 11/26/2002
Co-Innovator	Kevin Baum	Verification Complete 11/27/2002
Co-Innovator	Brian Classon	Verification Complete 11/26/2002
Co-Innovator	Mark Cudak	Verification Complete 11/27/2002
Co-Innovator	Vijay Nangia	Verification Complete 11/26/2002
Co-Innovator	Eugene Visotsky	Verification Complete 11/27/2002
Witness	Vip Desai	Acknowledgement Complete 11/27/2002, Notebook Not Signed
Witness	John Thomas	Acknowledgement Complete 11/27/2002, Notebook Not Signed
Manager	Joseph Nowack	Acknowledgement Complete 12/5/2002
Technical Reviewer	Jeff Bonta	Review Not Necessary

Reviewer Information

Role	Name	Action
Technical Reviewer	Jeff Bonta	
Grading Results		

Documents

Document Name	Description	Document Type	Uploaded By	Uploaded Date	Size
Relay015.pdf		Unspecified		26 Nov 2002	114.1 Kb

Questions

Name of Innovation or Engineering Development?
Base-enabled relay with distributed HARQ processing

What is the problem(s) to be resolved by or need(s) for your idea?
The link budget on the uplink is extremely challenging for broadband wireless systems due to :
a) a high thermal noise level (-101 dBm for a 20 MHz system)
b) FCC constraints that severely limit the maximum EIRP (e.g., 100mW for a portable unit)
The use of relaying techniques (using one or more repeaters) is very efficient at improving the link budget. However, a control mechanism of the relay by the BTS is needed.
Another major concern is how to perform hybrid ARQ (HARQ) with such an architecture, since

the entity in charge of the ARQ loop needs to know the soft information for IR or Chase combining. Therefore, there is a need for a mechanism to control the operation of relays which are activated only when needed, and a method to enable an efficient ARQ process.

What is the idea you are disclosing? Please provide a written description summarizing the idea. Please define all acronyms and other terms of art used.

The solution we propose is a base-enabled relay approach, where the operations of relays is triggered only when necessary. On the downlink, the user receives information from the BTS. On the uplink the information is relayed without the user being aware of it.

The necessary mechanisms to have this solution working (MCS selection, and HARQ process) are provided. General guidelines for the MAC implementation are also given.

How does this idea resolve the problem(s) or fulfill the need(s) in a new way?

The way the idea solves the problem is that the BTS always maintains control of the transmission. The user requests transmission on the RACH. The BTS evaluates the radio quality of the user<->BTS link and makes the decision whether or not to use a relay. If a relaying is used, the BTS then activates the relay(s) and assigns resources and modulation/coding schems to both the relay(s) and to the user. The user then transmits on its assigned resources, and the relay(s) retransmit(s) to the BTS on its(their) assigned resources. The HARQ process works as follows: the BTS is in charge of all the control signaling of the

HARQ process (e.g., request to send more parity bits), but all the HARQ buffering is done at the relay. When the relay has correctly received the frame, the information is re-encoded and sent to the BTS, which notifies the user of the succesful transmission.
In addition, mechanisms to perform HARQ with other types of relay (analog, "dumb" digital) are provided.

How or where will this idea be used (e.g. what process or product will it be applied to)?
The primary target is 4G cellular systems, but the idea can easily be applied to MBWA, 3G evolutions, or any system that uses relaying to increase coverage. The MAC solutions provided here are generic enough to be easily adapted to find any kind of digital wireless system.

Please enter one or more key words that may be used to identify your disclosure.

Is this disclosure a resubmission of a disclosure you have previously submitted?
NO

Please enter the forum from which this idea originated - e.g. Quest for Innovation, Advanced Inventing Session, Patent Scrub, etc. (Optional).

Is your idea known or has it been disclosed outside of Motorola without a duty of confidence (e.g., non-disclosure agreement, joint development agreement, etc.)?
NO

Has a product incorporating your idea been sold, offered for sale, placed in production, qualification, sampled, described in any publication (including Motorola promotional literature), marketed, shipped to anyone outside of Motorola (customer or distributor), or placed into inventory?
NO

What is the earliest verifiable date that you communicated your idea to an individual that is NOT an innovator (e.g., the date a non-innovator witness signed your engineering notebook)?
Nov 12, 2002

Was your idea created or developed through work performed with a consortium, alliance, government contract, university, or joint venture?
NO

Please specify the Export Control Classification Number(s) (ECCN) to which this disclosure pertains
Unknown

Standards

IEEE

Key Technologies

CORP - H7 Broadband Wireless(Beyond 3G)
CORP - H7 Self-Organizing Pervasive Networks
CORP - CT (N10) W-LAN/PAN

Innovators

Philippe J Sartori

The address and personal information for this innovator is restricted.

Commerce ID:	22207621	**Core ID:**	BPS005
Phone:	847/576-7181	**Fax:**	847/538-4593
Email:	Philippe.Sartori@motorola.com		
Department:	AE598	**Location:**	IL02
Mail Drop:	2928	**Manager:**	Joseph Nowack
Motorola Business:	CORP	**Business Unit:**	Motorola Labs - Borth/Yester

Kevin L Baum

The address and personal information for this innovator is restricted.

Commerce ID:	10047892	**Core ID:**	AKB001
Phone:	8475761619	**Fax:**	8475768378
Email:	Kevin.Baum@motorola.com		
Department:	AE598	**Location:**	IL02
Mail Drop:	2928	**Manager:**	Joseph Nowack
Motorola Business:	CORP	**Business Unit:**	Motorola Labs - Borth/Yester

Brian K Classon

The address and personal information for this innovator is restricted.

Commerce ID:	10120058	**Core ID:**	ABC007
Phone:	8475765675	**Fax:**	8475384593
Email:	Brian.Classon@motorola.com		
Department:	AE598	**Location:**	IL02
Mail Drop:	2928	**Manager:**	Joseph Nowack
Motorola Business:	CORP	**Business Unit:**	Motorola Labs - Borth/Yester

Mark C Cudak

The address and personal information for this innovator is restricted.

Commerce ID:	10036795	**Core ID:**	AMC005
Phone:	8475762573	**Fax:**	+18475768378
Email:	Mark.Cudak@motorola.com		
Department:	AE598	**Location:**	IL02
Mail Drop:	2928	**Manager:**	Joseph Nowack
Motorola Business:	CORP	**Business Unit:**	Blank

Vijay Nangia
The address and personal information for this innovator is restricted.

Commerce ID:	10136233	**Core ID:**	EVN003
Phone:	8475386725	**Fax:**	+1-847-538-4593
Email:	Vijay.Nangia@motorola.com		
Department:	AE598	**Location:**	IL02
Mail Drop:	2928	**Manager:**	Joseph Nowack
Motorola Business:	CORP	**Business Unit:**	Motorola Labs - Borth/Yester

Eugene Visotsky
The address and personal information for this innovator is restricted.

Commerce ID:	10118080	**Core ID:**	AEV016
Phone:	847/538-9458	**Fax:**	847/538-4593
Email:	AEV016@email.mot.com		
Department:	AE598	**Location:**	IL02
Mail Drop:	2921	**Manager:**	Joseph Nowack
Motorola Business:	CORP	**Business Unit:**	Blank

ver 2 Attorney-Client Privileged Upon Completion

Base-enabled relay with distributed HARQ processing

P. Sartori, B. Classon, E. Visotsky, V. Nangia, M. Cudak, K. Baum

Motorola Labs

Communication Research Labs

Version 0.91 November 25, 2002

1. INTRODUCTION

The next generation 4G cellular systems are anticipated to deliver much higher bit rates than today's systems. While many technology improvements such as advanced coding techniques or the use of incremental redundancy (IR) increase spectral efficiency, it is anticipated that 4G systems will require larger bandwidth than 3G systems. For instance, the CRL 4G proposal assigns 20 MHz for the uplink, while NTT DoCoMo is proposing bandwidths of 40 MHz.

The use of such large bandwidths poses a significant challenge for the uplink link budget: in a 20 MHz bandwidth, the thermal noise power is about –101 dBm. Furthermore, the FCC regulations for human exposure to EM radiations limit the EIRP power to 100 mW for a portable unit (unit near the head) or to 500 mW for a PDA unit (unit near the hand) [1]. With such constraints, and a cell radius of 2 miles, a portable device can only support a maximum bit rate of 20 kbps at a 3.7 GHz carrier frequency [1]. With a 2.5 ms frame, it would take about 250 frames (ignoring retransmissions) to transport a 1500 byte packet, resulting in a transmission time of over 500 ms [2], [3].

A promising way to improve link budget is to use *relaying techniques*: when a subscriber equipment (SE) is too far from the BTS, the information is sent first from the SE to a relay, then from a relay to the BTS. The relaying concept is illustrated in Figure 1. The general idea of using relays is gaining popularity. For instance, the relaying concept is proposed to extend the coverage of WCDMA systems using Bluetooth [4], [5].

Adding relays to the systems creates new constraints. In particular, a communications link must be established and maintained between the relay and the BTS, and between the relay and the SE. Also, the BTS must be able to control the activity of the relay: for instance, it has to be determined when and how the relay transmits, or when the relay needs to listen to a specific SE. Similarly, the BTS may choose to adapt the modulation and coding level for the particular relay to SE link. Therefore, the relay may need to perform channel quality measurements and report them to the BTS. Another major concern is how to perform hybrid ARQ (HARQ) with such an

architecture, since the entity in charge of the ARQ loop needs to know the soft information for IR or Chase combining. Therefore, there is a need for a mechanism to control the operation of relays which are activated only when needed, and a method to enable an efficient ARQ process. Finally, the cost of the relay needs to be low. Therefore, the architecture and protocols must be able to avoid any unnecessary processing at the relays.

This note aims at presenting a solution to perform relaying that allows inexpensive deployment of efficient relays.

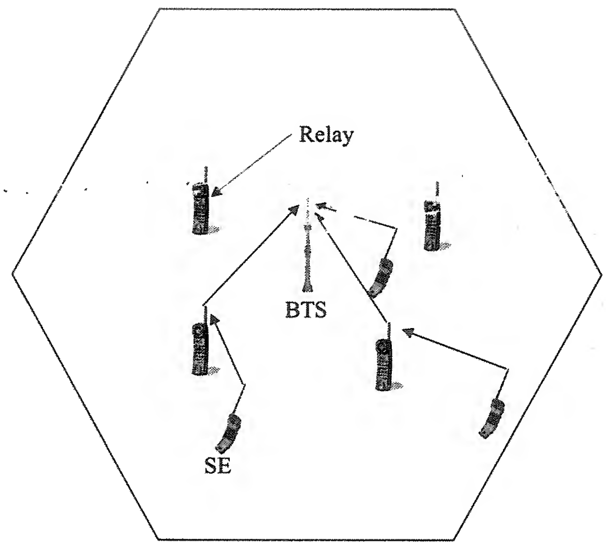

Figure 1. Relayed transmission.

2. BACKGROUND

Several technologies relate to the invention. First, the use of relays is known; they are used in various Private Mobile Radio systems (such as the Parrot system, developed by Salbu) for increasing coverage. These system configurations cannot support HARQ, and are not tailored for using Adaptive Modulation and Coding (AMC). In most of these system configurations, the relays are continuously on. In architectures where relaying is performed on-demand (by an other mobile unit), the relayed mobile is aware that it is relayed. Furthermore, relaying occurs both on the uplink and the downlink. From the relayed mobile's perspective, the relay functions as a BTS. Our architecture takes a different approach where relaying occurs on the uplink only and where the SE is not aware of being relayed. Furthermore, the SE does not need to send specific requests to the neighboring mobiles in order to be relayed.

Another field related to the invention is ad-hoc networking. This approach is totally decentralized, with each SE acting either as a relay or as a regular SE. This approach requires consider-

able messaging overhead between SEs. Furthermore, SEs acting as relays need to perform various layer2/layer3 tasks, such as scheduling and routing. Our approach relies on a relay that does not perform such high level tasks and that only requires limited MAC capabilities (to handle HARQ, as explained later in the document).

Yet another closely related art is the use of Bluetooth to extend the coverage of a cellular system [4]. In this approach, the SEs need to be aware of their neighbors. One SE creates a micro-cellular Bluetooth cell (scatternet) and acts as a local BTS (using the Master/Slave Bluetooth configuration). Unlike our invention, the SE acting as a Master needs to perform layers 2&3 tasks. Note however that some aspects of our invention could be applied to this concept, such as the HARQ process in relays.

The use of relays for extending coverage in a terrestrial cellular system is examined in [8]. Information-theoretic results on the use of relays for increasing capacity of wireless multi-hop communication systems are presented in [9].

In summary, the main differentiators of our invention compared with the related art are:

- The SEs do not need to probe their neighbors or other relays, and do not need to be aware that they are relayed.
- The relays do not need to be aware of other relays.
- The BTS always remain in control of the transmission, thereby resulting in increased transmission reliability.
- A way to perform HARQ for relayed transmission is provided.
- Mechanisms to select the MCS for a relayed transmission are provided.

3. GENERAL DESCRIPTION

The disparity in PA power between SE and BTS suggests an asymmetrical solution that assists uplink performance without providing the corresponding assistance on the downlink[1]. As a result, cost efficiencies may be achieved by creating a subordinate relationship between relays and the BTS allowing the relays to be low cost while ensuring robust reliable transmission supervised by a central authority. The cost efficiencies may be realized by reducing relay complexity such that it only focuses on layer-one operations and a minimal set of layer-two tasks. In addition, control messages do not have to be relayed – only bearer data. Moreover, the subordi-

[1] Relays typically provide the most benefit when used to improve coverage (i.e., they increase the spectral efficiency of a link from a low (zero) value to a moderate value rather than a moderate value to a high value). As the BTS transmit power is typically much larger than the SE transmit power, relays usually benefit the uplink more than the downlink.

nate relay (s-relay) configuration simplifies system deployment. System operators could deploy these s-relays in existing cells to address uplink coverage issues without having to re-address cell planning as might be required when adding microcells to achieve the same end.

3.1 System Configuration and Operation

Figure 2 depicts the possible communication pathways between BTSs, SE, and s-relays. Figure 2a) shows the typical communication paths in a cellular system with the s-relay disabled. A BTS coordinates the resources in the cell by distributing control information and arbitrating access requests. In addition, the BTS transmits bearer data directly to the SE and receives bearer data directly from an SE. Figure 2b) shows the communication paths with the s-relay enabled. In this case, the BTS still coordinates resources in the cell by distributing control information and arbitrating access requests. Additionally, the BTS continues to transmit bearer data directly to the SE. However, the uplink bearer data from the SE follows a triangular path first being received by the s-relay then repeated and received by the BTS. Figure 2 c) and d) show two variations on the s-relay configuration. Figure 2c) shows multiple active s-relays simultaneously repeating the SE bearer data to the BTS. Figure 2d) shows the simultaneous co-existence of a relayed and non-relayed uplink communication. A unique aspect of the s-relay configuration is that the SE may be completely unaware of the existence of a relay within in the system.

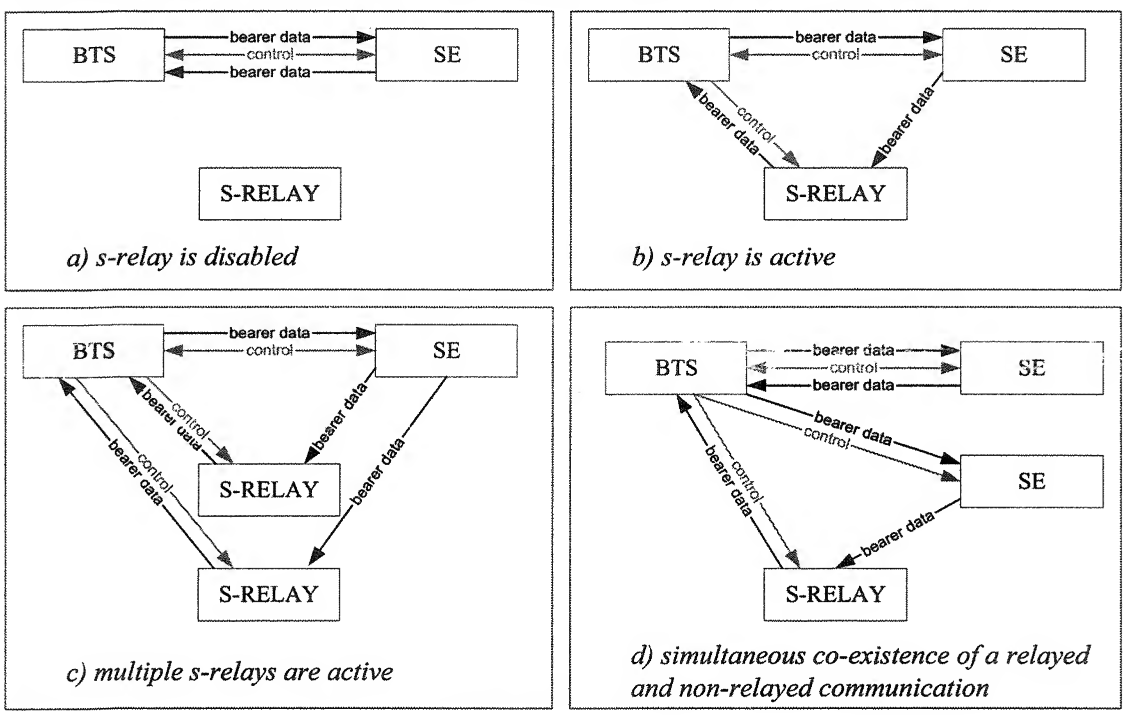

Figure 2 Communication pathways between BTSs, SE and s-relays.

The general s-relay method for facilitating adaptive transmissions comprises:

- Determining whether a relay is to be employed
- Providing a resource allocation and data rate to a transmission source, wherein
    - The resource allocation is provided by a transmission target (i.e. BTS)
    - When the relay is to be employed, the data rate accounts for the relay
    - When the relay is not to be employed, the data rate does not account for the relay
- Providing data to the transmission target

In the broadest sense, the above method is the minimum required to be able to potentially eliminate long (e.g., 250 frames) uplink bearer data transmissions between the transmission source (e.g., SE) and the transmission target (e.g., BTS). If the relay cannot be employed, the data rate cannot take into account the relay (and may remain 250 frames long). If the relay can be employed, the data rate can take into account the relay and be such that the transmission duration is of much shorter duration, as low as 10 or even 1 frame. As each data transmission is adaptive to the channel conditions, conditions may be such that even if a relay can be employed, it may not be employed if the direct link to the BTS is of sufficient quality. Typically, the determination of whether a relay is to be employed is made for each transmission, as might be appropriate is a system with mobile SE.

The relay (generally, one or more relays) is a subordinate relay (s-relay) because the resource allocation for the SE to relay link is provided by the BTS. The resource allocation includes the resources (e.g., time/frequency/code/space) required for a transmission, and may also (but is not required to) account for the relay. Both providing the data rate and the step of determining whether to employ the relay are typically done by the BTS, but there is at least one useful configuration where this is not the case.

Many of the options are standard relay configuration issues (e.g., relay band, relay timing), and many of the configurations are not preferred. A preferred implementation will be advantageous in terms of relay performance (HARQ location, AMC method), cost (buffers required, number of control channels to be decoded, minimize L2 tasks), and overhead (additional control messaging needed). Though HARQ is not required, providing a method of effectively performing HARQ (in addition to AMC) within the system is advantageous. While the method is described, the implementation will involve the BTS, SE, relay, and system.

An additional key differentiator for most configurations and the prior art is that the relays are base-enabled rather than dumb. A relay is enabled if it only transmits when the BTS tells it to, with the resource allocation for the relay to BTS link provided as needed. This is especially

useful when the relay band is in band (the relay and SE share resources) or when the out of band (the relay and the SE cannot share resources) resources are scarce or need to be closely managed. Note that MAC addressing is not required for non-enabled (dumb) relays. In addition, the 'known a priori' and 'determined by relay' relay resource allocations are usually by non-enabled relays. In this case, the BTS must decode the a priori resources or all possible resources that may be determined by the relay (typically out of band).

3.2 Preferred Embodiment: Base-enabled Decoding relay with distributed HARQ processing

The preferred embodiment for this invention is as follows:

1. SE requests transmission on the RACH. Although the transmission experiences severe path loss, the BTS is capable of receiving the signal due to a robust RACH design.
2. BTS receives signal from SE, determines path loss. Based on the computed path loss, and other parameters such as maximum delay, requested bit rate, traffic demand in the cell, the BTS makes the decision to enable the relay or not.
3. If BTS does not enable the relay, direct SE to BTS transmission occurs. END.
4. If BTS decides to relay the SE transmission, BTS sends a message to relays to trigger them to listen and relay the information from the SE. The message is Boolean and coded on one bit ("1"->turn relays on, "0"->turn relays off).
5. BTS assigns resources to SE. The resource assignment for the relay is implicit: the relay is assigned the same resources as the SE one frame later (this assignment is not the optimal in terms of spectral efficiency, but is easy).
6. SE transmits. All the relays listen.
7. Each relay demodulates and decodes the data, and checks the CRC. If the information is correct, relay re-encodes information using the same initial MCR assigned to the BTS and sends it to BTS on its assigned channel resources. If not successfully decoded, relay stores the soft information and does not send anything to the BTS.
8. (partially occurs concurrently with 7). BTS listens on assigned channel resources for the relay. If it does not receive anything, go to step 5 to assign resources for the next retransmission. If it receives data, it decodes it and processes the information[2]. END.

[2] An error control mechanism between the relay and the BTS needs to be provided. However, in this embodiment, it is assumed that the relay->BTS link is much better than the SE->relay link so that the BTS is able to successfully decode the data coming from the relay using the initial MCR assigned to the SE.

The flow charts describing the operation of the BTS, the relay and the SE are given in Appendix A (Flowchart 1 for the SE, Flowchart 2 for the relay and Flowchart 3 for the BTS. Note that Flowchart 1 ***always*** describes the flow of operation for the SE, no matter what the embodiment of the invention is.

Note that an alternate lower cost variant of this embodiment uses a relay that demodulates (but does not decode) the data. In this case, soft Chase combining can be applied at the relay.

3.3 Alternate preferred embodiment 1: Base enabled Waveform Relay with Centralized HARQ

This embodiment uses analog relays (or a digital equivalent) and works as follows:

1. SE requests transmission on the RACH. Although the transmission experiences severe path loss, the BTS is capable of receiving the signal due to a robust RACH design.
2. BTS receives signal from SE, determines path loss. Based on the computed path loss, and other parameters such as maximum delay, requested bit rate, traffic demand in the cell, the BTS makes the decision to enable the relay or not.
3. If BTS does not enable the relay, direct SE to BTS transmission occurs. END.
4. If BTS decides to relay the SE transmission, BTS sends a message to relays to trigger them to listen and relay the information from the SE. The message is Boolean and coded on one bit ("1"->turn relays on, "0"->turn relays off).
5. BTS assigns resources to SE. The resource assignment for the relay is implicit: the relay is assigned the same resources as the SE one frame later.
6. SE transmits. All the relays listen.
7. All relays simultaneously retransmit the *received waveform*. All relays of a given SEs transmission will arrive at the BTS (with different multipath profiles and additional frequency diversity, hopefully all within the cyclic prefix of an OFDM system) contributing to the signal energy.
8. BTS listens on assigned channel resources for the relays, decodes and demodulates the data. It processes the information and performs the HARQ process. END.

Note that for this embodiment, HARQ is performed in a centralized fashion at the BTS (buffers, combining, and control). Any method of SE resource allocation may be used. The operation of the relay is described in Flowchart 4, and the operation of the BTS is described in Flowchart 5.

3.4 *Alternate preferred embodiment 2: Non-enabled Out of Band Waveform Relay with Centralized HARQ*

This embodiment is preferred when many very inexpensive relays must be deployed and used extensively, and a paired band is available for deployment. One of the bands contains the normal system deployment (TDD), and the other paired band contains the relayed transmissions. A key benefit (low cost) of the relays is they do not have to observe control signaling from the SE or BTS. It occurs as follows (the flowcharts are given in Appendix A3):

1. SE requests transmission on the RACH. Although the transmission experiences severe path loss, the BTS is capable of receiving the signal due to a robust RACH design.
2. BTS receives signal from SE, assigns resources to the SE. Based on the received signal strength, BTS decides to listen to relayed signal or not.
3. If BTS decides to listen to signal coming from SE, direct SE to BTS transmission occurs. END.
4. Each relay (which may have directional receive antennas) measures signal strength and decides (typically via threshold) to repeat the frame. The data (which may have more than one SE data) is retransmitted on the other band with a predetermined time offset.
5. If BTS has made the decision to listen to relays, it listens to the resources where the relays transmit. All relays of a given SEs transmission will arrive at the BTS (with different multipath profiles and additional frequency diversity, hopefully all within the cyclic prefix of an OFDM system) contributing to the signal energy.
6. BTS listens on assigned channel resources for the relays, decodes and demodulates the data. It processes the information and performs the HARQ process. END.

The operation of the relay is described in Flowchart 6, and the operation of the BTS is described in Flowchart 7.

With this embodiment, the decision to relay can be per frame or per baud, since there is no explicit enabling of the relays. HARQ is performed in a centralized fashion at the BTS (buffers, combining, and control. Note also that the BTS can use an additional diversity gain by combining the signal it directly receives from the SE with the signal coming from the relays.

Note that various enhancements are possible to the basic operation and will be discussed in the sub-sequent sections

4. SE RESOURCE ALLOCATION

The benefit of the s-relay solution can be greatly enhanced by adapting the modulation and coding (AMC) level of the initial SE transmission to reflect the more favorable propagation conditions between SE and s-relay. Without the relay present, the SE determines the maximum AMC[3] level based on measurements of downlink transmissions from BTS pilots. To support AMC adaptation with respect to the SE to BTS, one of following methods may be employed.

4.1 Blind AMC Selection

A blind AMC selection could be made by the BTS based on some open-loop approximation. The simplest method of AMC selection would be to use an aggressive default value with the hope that the SE is close to either one of several s-relays or the BTS. Alternatively, the AMC selection could be based on the BTS to SE channel. In this case, a fixed s-relay improvement factor may be added to each BTS to SE path loss estimate. As a result a more aggressive AMC level would be selected. This latter solution could be especially appropriate if a set of s-relays were distributed in a circle with the BTS at the center. In all cases, the system may rely on Hybrid ARQ and retransmission to mitigate all poorly chosen AMC levels.

4.2 S-Relay Beacon

A special s-relay beacon transmit period can be added to the MAC frame. All relays and the BTS transmit this beacon. The SE would be required to measure this beacon and base it's AMC level selection on this measurement. The SE would then report the selected AMC level (and best s-relay for enabled) to the BTS during an access request. Two possibilities exist for beacon processing and measurement.

- *Unique Relay Beacons*—the beacons transmitted by the relays can be structured so that the SE may differentiate them. For example, the beacons may be orthogonal using time or code multiplexing. Alternatively, the SE may employ joint detection to separate the uniquely identifiable beacons. Finally, the SE may use adaptive antenna techniques to differentiate between SEs based on their spatial path (e.g. angle of arrival). In all cases, the SE would be able to measure each relay's beacon independently, select the optimal relay, and then base it's AMC selection on the beacon from the optimal relay.
- *Indistinguishable Relay Beacons*—the beacons transmitted by the relays may be identical or sufficiently similar so that it is impractical for the SEs to differentiate them. In this case, the SE could base it's AMC selection based on the combination of all beacon signals. For example, the SE could simply measure the received signal strength of the bea-

[3] For IFDMA, the SE determines both minimum RPF and AMC level.

cons. Alternatively, the SE could jointly demodulate the beacon treating beacons from difference relays as multipath from a single relay. The selected AMC level would be slightly optimistic and may require that *all* the relays be activated. Therefore the SE may use a degradation factor to reduce its selected AMC level. This degradation factor could be broadcasted by the BTS based on the relay density, or simply guessed by the SE. Another (better) possibility would be to forgo the degradation factor and simply rely on HARQ re-transmission to mitigate any inaccuracies in the AMC selection process (similar to blind AMC). Another possibility is to use a higher AMC level than the one based on the received signal power to account for any possible max-ratio combining gains (by measuring the signal power, the SE cannot do better than equal gain combining).

4.3 S-Relay Channel Quality Reporting

S-relays can monitor the uplink traffic such as the access request messages and then provide a channel quality report to the BTS. In order for this to work, the s-relays must know the SE transmit power. To this end, the access request messages could be modified such that the SE explicitly identifies its transmit power.

5. RELAY ACTIVATION

Two types of relay activation are provided:

- *Based-enabled relay*. In that case, the BTS determines when to activate relays, and possibly which one(s) to activate. The relay does not transmit, unless turned on by the BTS. The BTS enables one or more relays when it believes the SE and system would benefit from the relay. The BTS makes some sort of control communication to enable the relay – the relay is not 'always on', for example. This may be especially important when trying to conserve bandwidth or limit system interference. BTS receives signal from SE, determines path loss. Based on the computed path loss, and other parameters such as maximum delay, requested bit rate, traffic demand in the cell, the BTS makes the decision to **enable** the relay or not.
- *Dumb relays*. This type of relay is not enabled by the BTS. The relay measures the amount of energy it receives. If the amount of received energy is larger than a threshold, the relay transmits it to the base, and remains silent otherwise. The BTS will then combine the transmission from all s-relays and demodulate the data.

6. MAC ADDRESSING

6.1 Arbitration

A key advantage of the s-relay solution is how easily it might be integrated into an existing MAC. The BTS needs to be able to control the relays, based on pre-defined arbitration rules, as described below.

In a system with multiple s-relays, the BTS may determine an appropriate sub-set of s-relays used to repeat the SE transmission. There are many good reasons to limit the number of s-relays in a system that repeat the SE data. First, as relays use system resources, it may be beneficial for the BTS to disable the relays when the SE may be close to the BTS or the channel quality between the SE and BTS is good for reliable transmission of the SE data. Second, an s-relay may be far away from the SE and have poor reception of the SE's original data burst and therefore be unable to provide a substantive assistance. Third, the s-relay processing or buffering resources may be limited, therefore, the BTS may need to ration the s-relay's services. Fourth, thousands of s-relays could cause interference to increase, despite directional tx and rx. Regardless of the reason, one or combination of the methods in the following sub-sections may be used to arbitrating which s-relays are active. The types of arbitration considered here are presented below:

- *No Arbitration:* the simplest solution is no arbitration. It is possible to allow all s-relays to repeat the SE tranmission's data burst. When relaying is enabled, all s-relays will receive the SE's data burst, and perform an analog or similar retransmission of the SE's data burst. The BTS will then combine the transmission from all s-relays and demodulate the data.
- *Distributed Arbitration*: a slightly more complicated approach than the no-arbitration method is where all s-relays make an independent judgment as to whether they should repeat or not. In this case, all s-relays monitor the SE's data burst, measure the received C/I ratio and then compare it to threshold. If it is above a threshold they repeat SE's data burst otherwise they remain silent. As with the no arbitration case, the BTS will combine the transmissions from all s-relays who have elected to demodulate the data.
- *Diversity Decoding Arbitration*: All s-relays may attempt to decode the SE data burst. The first SE to successfully decode the SE data informs the BTS. If multiple s-relays are simultaneously successful, the BTS selects one s-relay to repeat the data if the direct SE transmission fails.

6.2 Addressing

Several possible solutions exist with varying complexity depending on which set of arbitration rules is chosen:

- *Boolean S-Relay Control* (the simplest scheme)—S-relay activity can be triggered using an existing Uplink Assignment Control Channel (UACCH). Only one additional bit would be needed to control the s-relay operation ("0"-> turn relay off, "1"->turn relay on). The s-relay could snoop all the other information regarding the waveform to be repeated (e.g. IFDMA repetition factor and offset) from the standard UACCH message sent to the SE.
- *Addressed S-Relay Control*—when multiple s-relay are deployed and it is required that the BTS selectively enable these relays; a multi-bit field must be added to UACCH message. This multi-bit field could contain an s-relay ID or alternatively one bit per s-relay. However, a means of arbitrating between s-relays would be required (cf arbitrating section).
- *Direct S-Relay Control*—another alternative would be to control s-relays using the same control structures that are used to communicate to SEs. With this approach, these s-relays could be solicited to repeat the information prior to or after the original bearer data transmission. For example, the system might be configured such that the s-relays are blindly buffering all data. A BTS may attempt to decode the original SE transmission directly. If unsuccessful, the BTS could retrospectively solicit the s-relay to repeat the preceding transmission.

Many optimizations of the MAC protocol are possible and can be tailored to match the particular air-interface technology (IFDMA, CDMA, OFDMA, TDMA, etc). Some optimizations for the 4G MAC may include implicit assignment of uplink resources using Boolean S-Relay Control. For instance, the relay could get the same baud assignment on frame N+1 that the SE has on baud N, with the same coding rate (or the relay could have a pre-defined rate used by default).

7. RELAY PROCESSING

Depending on the relay complexity, and/or type, three types of relay processing are considered:

- *Waveform* processing. This type of processing is the simplest possible. The received signal is not demodulated. The relay receives the signal and only performs operation on the modulated signal (such as adding delay, changing the carrier frequency, amplifying the received signal). It can be performed by an analog relay, or by a digital equivalent.
- *Demodulation* processing. The relay needs to be digital. The received signal is demodulated, but not decoded. This type of processing is useful is for instance Chase combining is done at the relay. The signal sent to the BTS uses the same coding scheme but can use a different modulation scheme.

- *Demodulation and decoding.* This is the most advanced type of receiver. The relay decodes the received bits, and can perform advanced tasks such as IR or CRC checking. Note that a different MCS scheme can be used on the relay-> BTS link.

Being able to use a different modulation and/or a different coding scheme on the relay->BTS link is very important. For instance, if the SE uses QPSK rate ½ , and the relay uses 64QAM rate ½, the relay only needs to transmit 1/64th of the time. If the relay and the SE share the same band (in-band transmission), this results in increased transmission rates since the SE needs to be silent only one every 65 transmission time units.

Need to discuss the MCS of that link somewhere. Note that decoding may have to peak into a piggyback, which is undesirable.

8. HARQ

HARQ, and especially Incremental Redundancy (IR) can be problematic when a relay is used. Relays that decode and re-encode the SE transmission usually destroy the soft information needed for HARQ process. In this section, two ways to perform HARQ with relays are described.

8.1 Centralized HARQ.

All the HARQ process is done at the BTS. The relay receives the signal and performs waveform processing. The waveform is conveyed to the BTS that makes the soft-combining. Typically, the relay->BTS link can be made much better than the SE->relay link (by the use of e.g., directional antennas). In that case, the signal received at the BTS is only slightly altered compared with the signal received at the relay.

Another type of centralized HARQ processing can be performed. The relay demodulates the signal, computes the LLR, encodes the LLRs, and sends the LLRs to the BTS. Assuming that the soft information is coded on 4 bits, the relay->BTS link must have a spectral efficiency at least 4X greater than the MS->relay link. The relay might have to use a higher MCS or more bandwidth. In addition, the BTS needs to be aware that it receives the LLR instead of the actual bits. Nevertheless, this solution is feasible if e.g., the relay->BTS signal is conveyed on a wired link (optical fiber).

Note that the condition *sine-qua-non* to perform centralized HARQ is to have a *very* good relay->BTS link. Therefore it is not applicable all the time.

8.2 Distributed HARQ

The key difference with the way HARQ is usually done and the proposed method is that the HARQ memory is not co-located as the HARQ control signaling. The HARQ buffering and

combining is performed at the s-relays with the control signaling provided by the BTS thereby resulting in a distributed HARQ process with centralized control. Two possible decentralized mechanisms can be done:

8.2.1 DECODING PROCESSING

This mechanism can handle both IR and Chase combining. The HARQ process can be done as follows (and is also described in Flowchart 8):

1. BTS triggers s-relay(s) on the downlink to repeat the uplink transmission (and to take care of the ARQ buffering. – this should be known not triggered)
2. SE transmits. Relay receives.
3. Relay demodulates and attempt to decode received signal based on the received LLRs and on the previous HARQ buffer state stored at the relay (if this is not the first transmission).
4. If unsuccessful decoding, relay sends nothing to the BTS (or dummy bits to notify the BTS that transmission is not complete, or the necessary reliability information…). Relay buffers the received LLRs. The BTS notifies the MS to send a retransmission. Transmission process goes back to step 2.
5. If successful decoding, the relay sends the frame to the BTS.

Step 5 is easy to perform, since the relay<->BTS link is anticipated to be much better than the SE<->relay link, since it is a fixed wireless access link. The preferred solution is that the relay sends the information to the BTS using the same encoding rate as the SE initially used. If the relay<->BTS link were not good, a traditional HARQ process could be used but would add additional delay

Note that this process works even if more than one relay is activated since the BTS is always in control of the transmission. For instance, the diversity decoding arbitration rule (described in Section 6.1) can be applied.

In order to perform the HARQ decoding, the relay must be aware of the modulation and coding rate. The modulation and coding rate can be contained as part of the assignment, UACCH. Alternatively, part of the coding rate may be conveyed in the SE request on the RACH (e.g. the information block size). Therefore, the relay may acquire knowledge regarding the modulation and coding rate by listening to the UACCH transmission and the SE access request. Alternatively, the BTS may inform the relay of the contents of the SE access request (e.g. the information block size) as part seperate relay activation control message. This latter method assumes that the relay is receives an independent message for activation.

8.2.2 DEMODULATING PROCESSING

This mechanism is suitable for Chase combining only.

1. BTS triggers s-relay(s) on the downlink to repeat the uplink transmission (and to take care of the ARQ buffering. – this should be known not triggered)
2. SE transmits. Relay receives.
3. Relay demodulates received signal and combines it with the received LLRs and on the previous HARQ buffer state stored at the relay (if this is not the first transmission).
4. Relay sends the combined frame to BTS.

9. RELAY RESOURCE ALLOCATION

Five types of relay resource allocation are considered:

- *Explicit* resource allocation. The relay is notified of which resources to use by the BTS using the UACCH. Alternatively, the resource assignment may be conveyed over an alternate control channel (e.g. a separate channel may be more suitable for out-of-band transmissions).
- *Implicit* resource allocation. The resources the relay uses are tied to the resources the SE uses. For instance, if the MS is assigned frame N, the relay can be assigned a fraction of frame $N+1$. The fraction is determined based on the MCRs the SE and the relay use e.g., if SE uses QPSK ½ and relay uses 64QAM ½, the relay is assigned $1/64^{th}$ of frame $N+1$.
- *Known a-priori* resource allocation. The relays always know which resources to use. This is particularly relevant for the MCS assignment. The relay->BTS link is tailored to support a given MCS, and this MCS is always used by the relay (and the BTS is aware that this relay will always use this given MCR).
- *Determined-by-relay* resource allocation. When the relay needs to transmit, it sends a transmission request to the BTS. For instance, if the relay takes care of the HARQ buffering, the relay needs not to transmit until the decoding is done. When the decoding is successful, the relay can request transmission. By transmitting only when needed, the relay reduces interference and does not waste bandwidth.

Note that the relay resource allocation process can combine several of these schemes. For instance, the MCS can be known *a priori*, whereas the frame to use can be implicitly assigned (or any variations thereof).

10. RELAY BAND

The relay can either share the band with the SE ("in-band" transmission) or use another band ("out-of-band" transmission). In the case of in-band transmission, the duty cycle cannot be 100%, since the relay cannot simultaneously transmit and receive on the same frequency). For out-of-band transmission, there is no such limitation, however more bandwidth is needed (although an unlicensed band, such as the NII band can be used).

In-band and out-of band transmissions are illustrated in Figure 3.

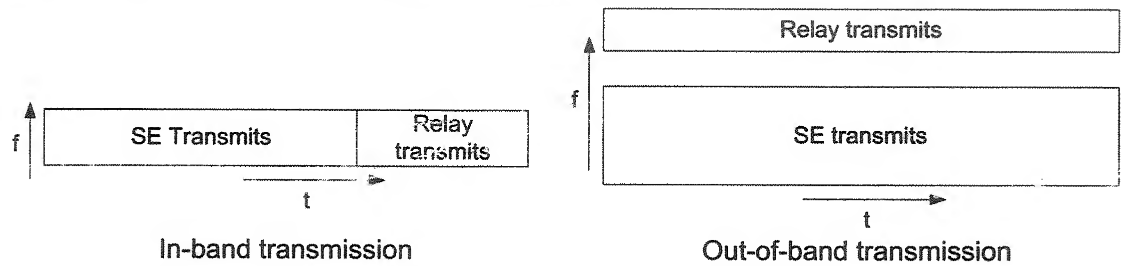

Figure 3. In-band and out-of-band transmission.

11. RELAY TIMING

The medium used by the s-relay to repeat the SE's transmission has significant bearing on the timing of events. For example, if the s-relay uses in-band transmission to repeat the SE data, the s-relay must delay the repeated transmission until the original transmission completes[4]. As a result, the s-relay must store-and-forward the SE data burst by buffering the original SE data transmission and then transmitting in a subsequent frame[5]. However, if the s-relay uses out-of-band transmission (e.g. wired backhaul, alternate RF band) the s-relay may repeat the SE transmission with relatively small delay such that the MAC would perceive it as concurrent with the original transmission. Even with out-of-band transmission, other factors may require that the s-relay store-and-forward the SE data burst. In practice, the MAC protocol only needs to consider

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[4] Perfect isolation of transmit and receive antenna in close proximity is not possible. As result, the transmitter of a single frequency device will overwhelm, if not damage, the receiver when operated simultaneously.

[5] The data may be buffered and repeated in a variety of formats. The s-relay may simply store samples of the analog waveform and repeat them. Alternatively, the s-relay may demodulate and decode the data, and re-encode in a more efficient (e.g. higher modulation format).

two cases: a store-and-forward relay configuration (SFRC) and a concurrent relay configuration (CCRC).

Figure 4 contains message sequence diagrams (MSD) (a.k.a. bounce diagrams) to illustrate some of the timing relationships and messaging discussed in this section. Superimposed on these bounce diagrams is the structure of the TDD 4G MAC frame [question – how do these apply to FDD?]. The shading and coloring indicates various sub-intervals within the MAC frame and is identified in the legend. Figure 4a) shows the timing relationship of a standard uplink transmission without the s-relay enabled; Figure 4b) shows the timing relationship of a uplink transmission with a SFRC enabled; Figure 4c) shows the timing relationship of a uplink transmission with a CcRC enabled; and Figure 4d) shows the timing relationship of a SFRC enabled transmission with retrospective solicitation to repeat data.

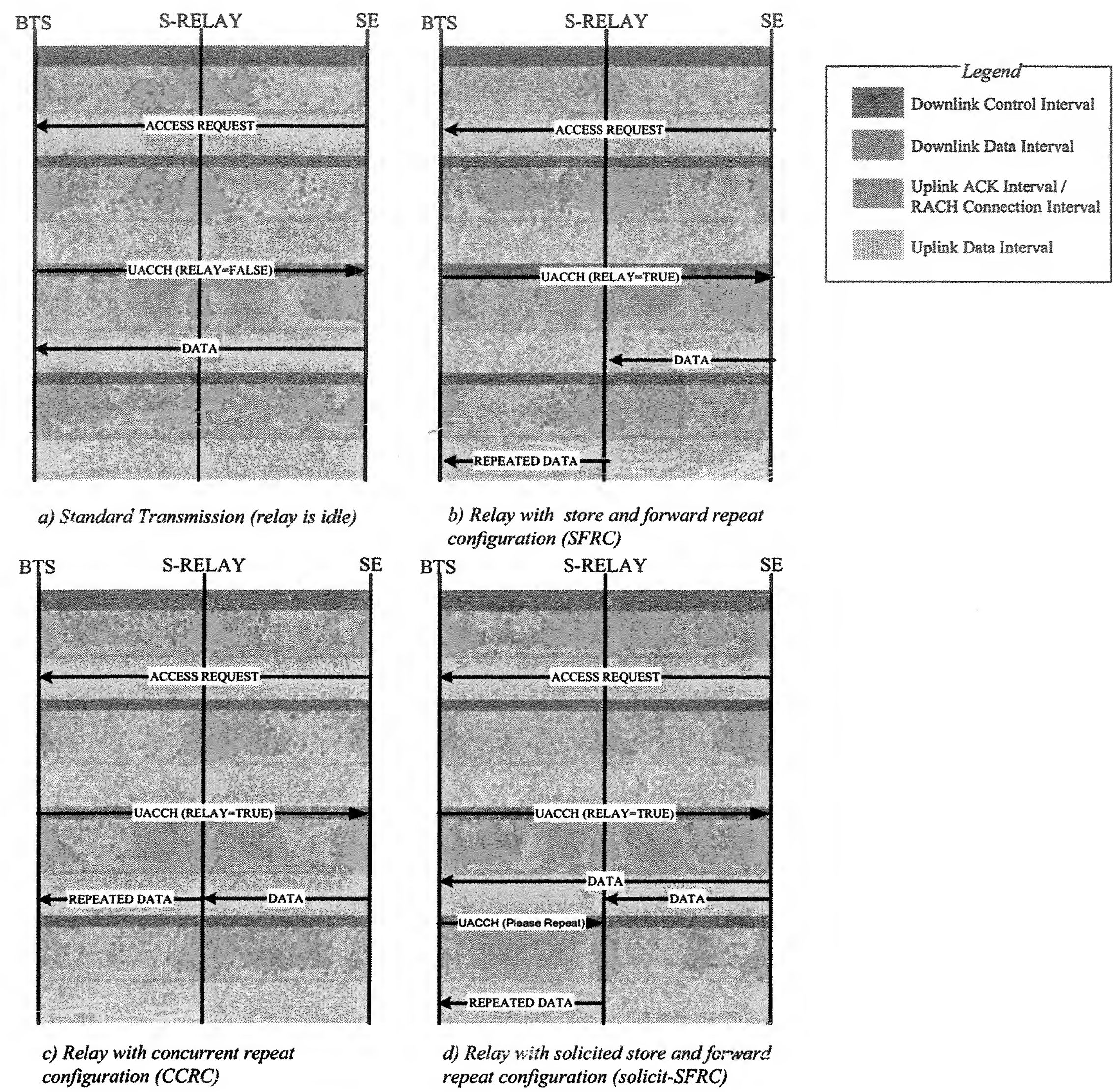

Figure 4 Message Sequence Diagrams illustrating MAC timing relationships.

Some improvements can be done to these two basic configurations. For instance, Figure 5 shows an example of a system with a relay in store and forward configuration. As can be seen from Figure 5, the transmission from SE to s-relay is also received by the BTS (label 'copy 1') and the BTS may attempt to decode it. If the decoding fails, the BTS may combine the original SE transmission (copy 1) and the repeated transmission from s-relay (copy 2) thereby improving the received SNR. The improvement in reliability (probability of decoding successfully) depends on the method used for AMC selection.

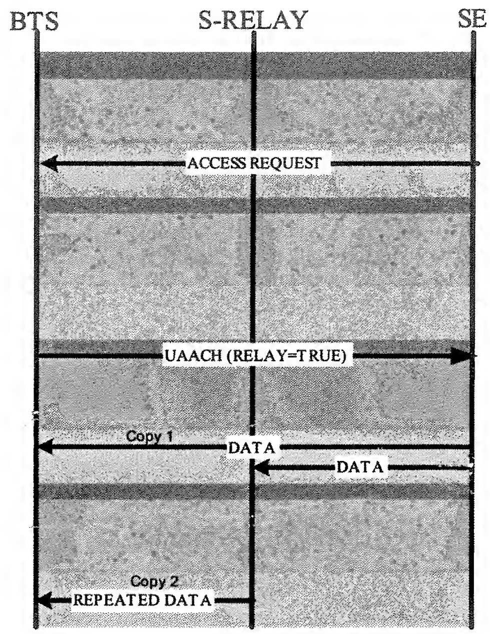

Figure 5 Message Sequence Diagram of relay with store and forward repeat configuration (SFRC).

12. RELAYING ON THE DOWNLINK

12.1 General Description

While relaying is primarily used for the uplink, the same base-directed relay activation mechanism can be triggered for the downlink as well. For 4G, one of the cases is when the SE<->BTS link experiences long delay spread, so that the cyclic extension is too short to deal with it, thus resulting in large performance degradation. Note that this was observed during the 4Gx data collection process, and was reported in [7] (Tower road and Meacham road). The general process is as follows:

1. SE transmits.
2. BTS computes the amount of the channel response occurring after the cyclic prefix extension (using [6]), and detects significant energy outside the cyclic extension.
3. BTS activate the s-relay(s) on the downlink.
4. BTS sends the transmission schedule to both the s-relay(s) and the SE.
5. BTS transmits/relay repeats. The BTS detects that the SE is out of the blind spot as the excess delay is smaller than the cyclic prefix (with the excess delay spread detector).

Note that the same improvements as for the uplink can be implemented such as e.g., mechanisms to trigger a limited number of relays (probably one relay is enough on the downlink). MAC Implementation

Processes similar to what was described in Section 6 could be implemented. Another bit is needed to indicate that the relaying needs to be performed on the downlink.

13. CONCLUSION

A base-directed relay activation mechanism was presented: the BTS is always in control of the transmission, the relay(s) is (are) triggered only when necessary. In addition, the SE needs not to be aware of the relaying process. Different relaying options are presented. While relaying is mainly useful for the uplink, it can also be applied to the downlink as well to increase capacity by reducing the length of the cyclic prefix.

Various mechanisms to enable HARQ and to select an MCS for a relayed transmission were presented.

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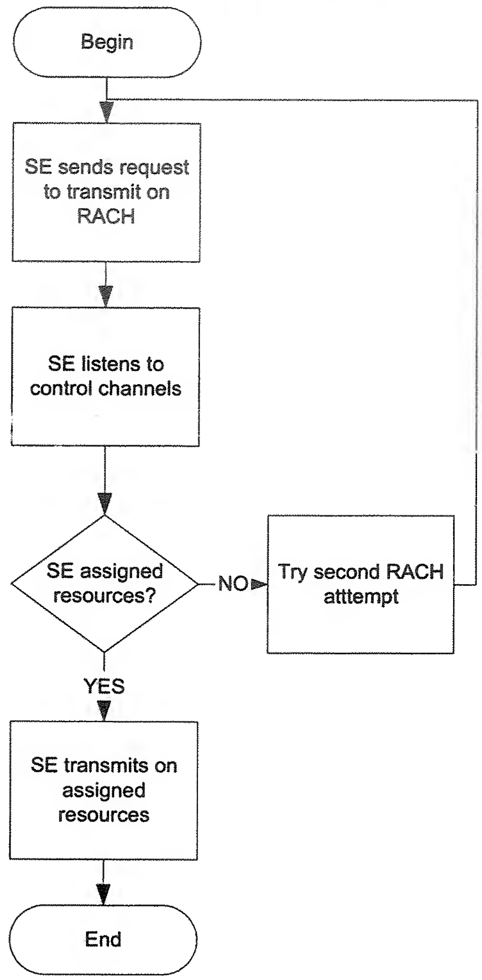
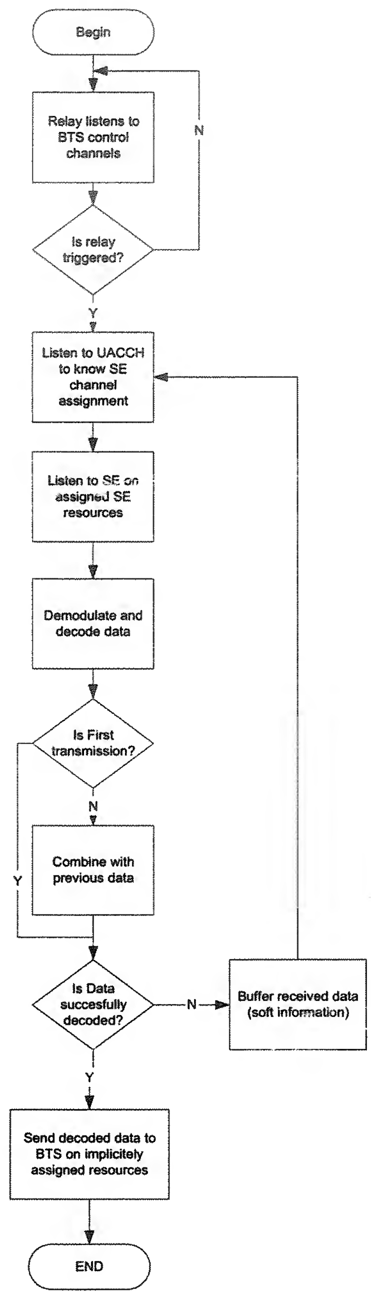
[9] P. Gupta, P.R. Kumar, "The Capacity of Wireless Networks," *IEEE Transactions on Information Theory*, vol 46, March 2000.

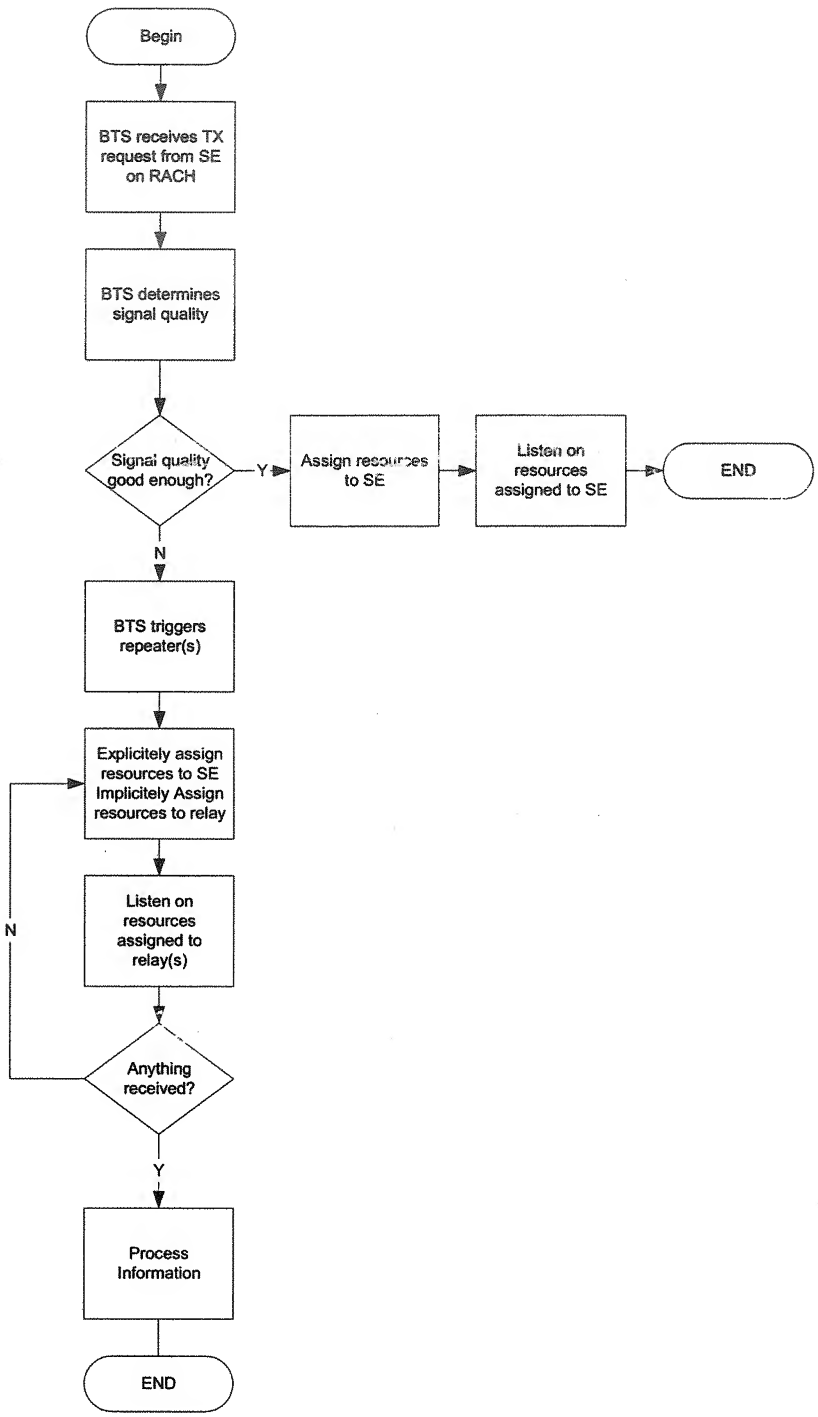
APPENDIX A: FLOWCHARTS OF OPERATION.



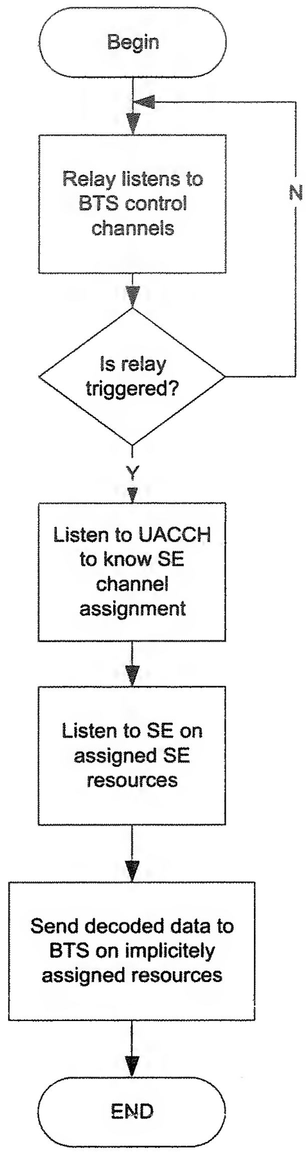
Flowchart 1. Flow of operation for the SE for *all* the relaying schemes.



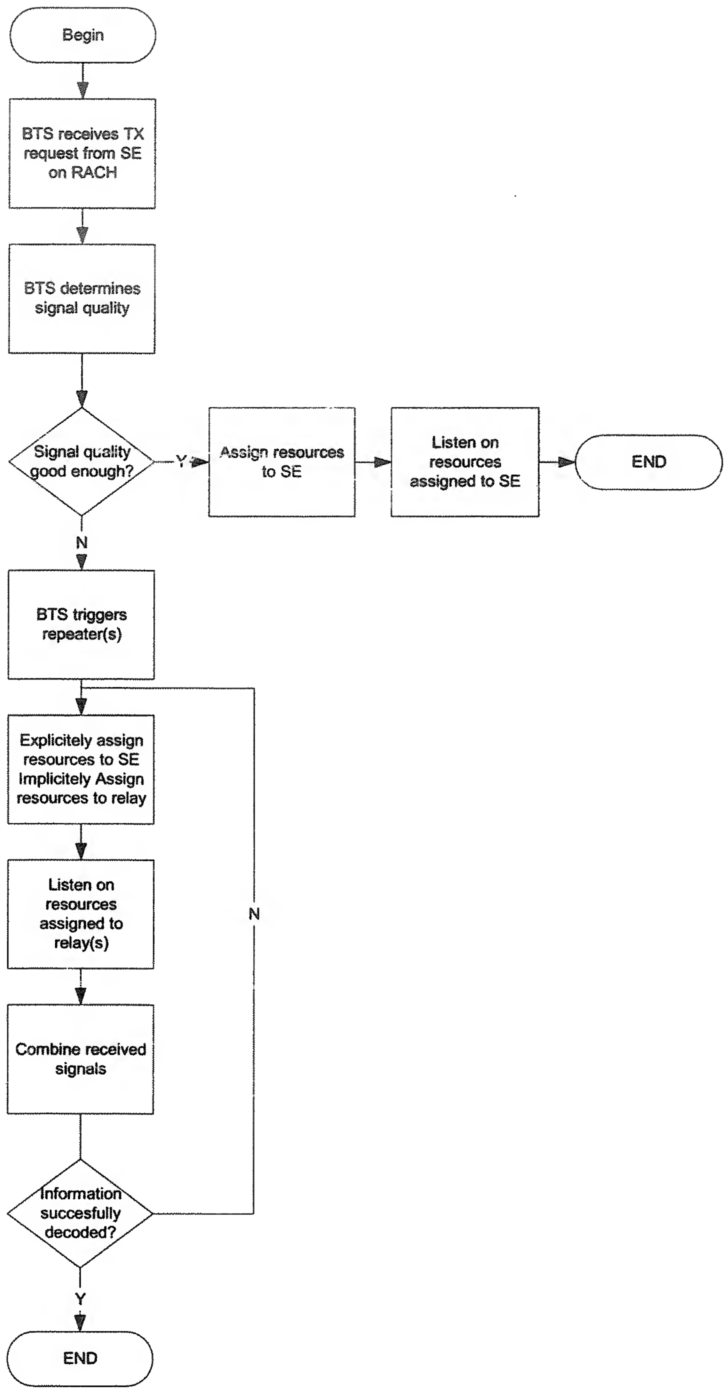
Flowchart 2. Flowchart of operation for the relay, for the preferred embodiment.



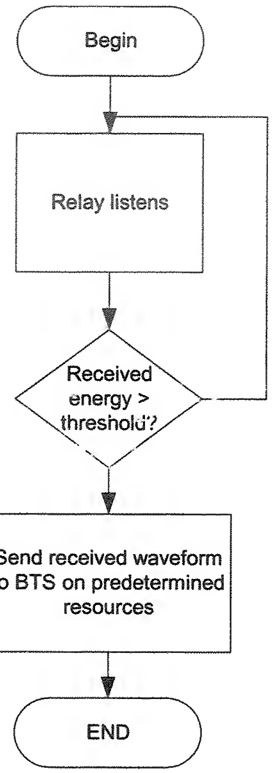
Flowchart 3. Flowchart of operations for the BTS, for the preferred embodiment.



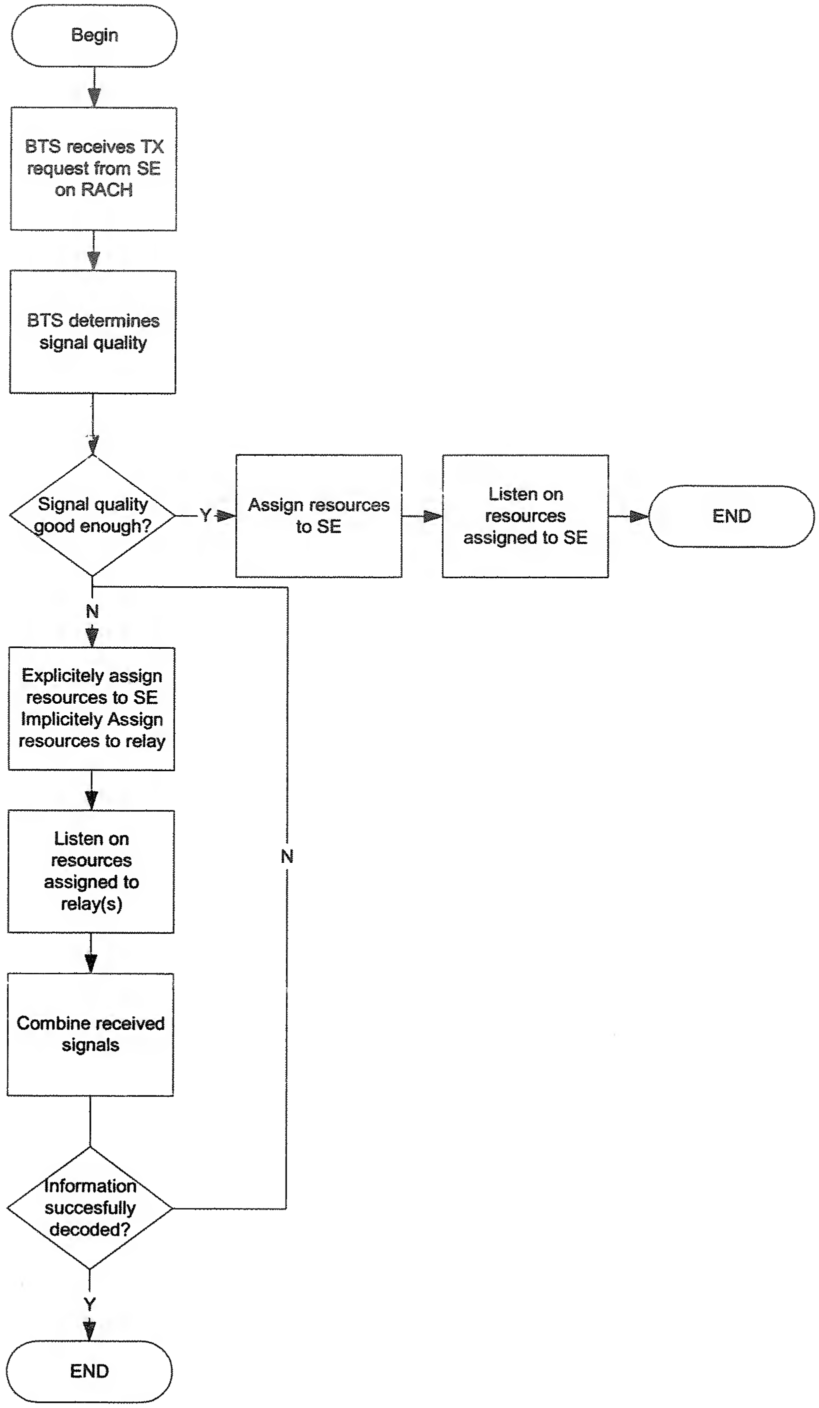
Flowchart 4. Flowchart of operations for the relay, for the first alternate embodiment.



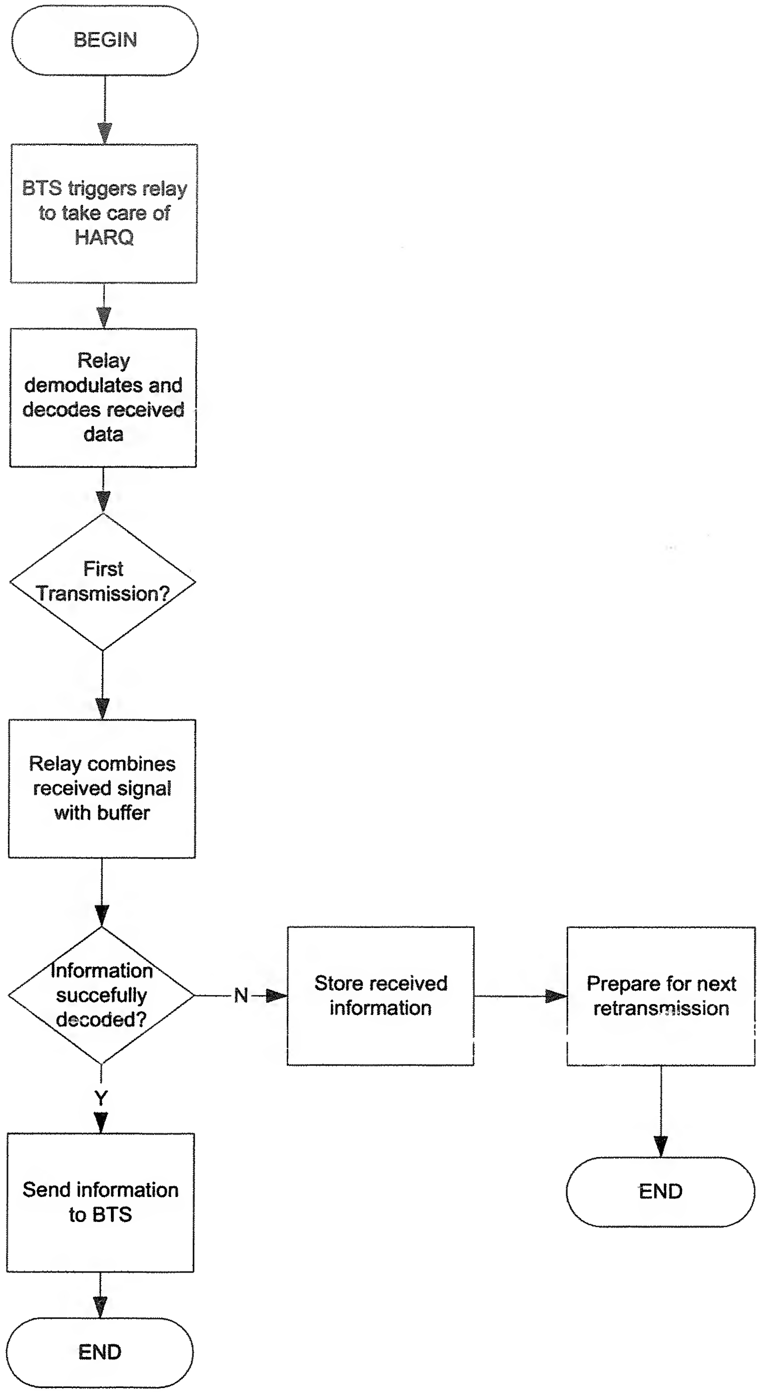
Flowchart 5. Flowcharts of operations for the BTS for the first alternate embodiment.



Flowchart 6. Flowchart of operations for the relay for the second alternate embodiment.



Flowchart 7. Flowchart of operations for the BTS for the second preferred embodiment.



Flowchart 8. Relay operation with HARQ (demodulation and decoding).